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(71) Applicant (*for all designated States except US*): XAAR LIMITED [GB/GB]; 2 Science Park, Milton Road, Cambridge CB4 4FD (GB).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): PATON, Anthony, David [GB/GB]; The Thatched Cottage, 51 Mills Lane, Longstanton St Michael, Cambridge CB4 5DW (GB).

(74) Agent: GARRATT, Peter, Douglas; Mathys & Squire, 100 Grays Inn Road, London WC1X 8AL (GB).

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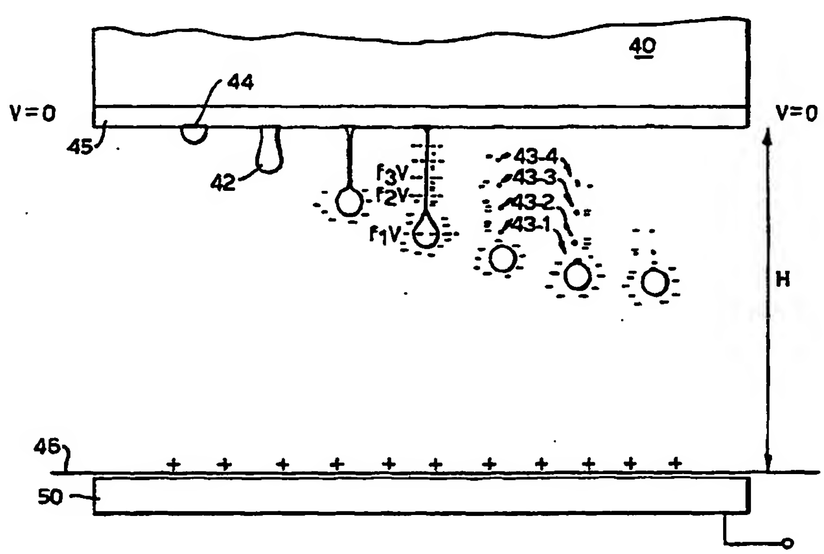

(57) Abstract

To control the velocity of ink drops ejected from nozzles of a drop-on-demand printer, an electrical field is established along the nozzle axis. An electrical charge is induced in the drops, possibly using the same field, and the drops are accelerated by action of the electric field on the charge retained by the drops. In this way, satellite drops can be caused to accelerate toward the principal drop in flight. Also, in a greyscale printer, it is possible to compensate for differential air drag between differently sized drops.

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DROPLET DEPOSITION APPARATUS

The present invention relates to droplet deposition apparatus and especially to drop–on–demand ink jet printers.

In the operation of drop–on–demand printers of the type where ink drops are ejected by generating a pressure pulse in chambers behind the nozzles of a nozzle plate, the emerging drop trails a fluid ligament between the drop and the meniscus in the nozzle. Particularly at higher fluid velocities defined by We>5 (where We is the non–dimensional velocity or Weber number), the ligament breaks up following break–off of the principal drop into one or more following satellite drops. There is a tendency for some of those satellite drops to fall back on to the printhead and nozzle plate. Prevention of ink collecting on the nozzle plate from this source is a significant consideration concerning the printer hygiene and printhead reliability. Under conditions when a regular deposit of satellites occurs, the nozzle plate requires to be wiped regularly with a wiper to maintain good and reliable print quality.

Also in the operation of drop on demand printers it has been proposed to effect variable tone printing by ejecting variable sized drops. A suitable range of tones for example may be provided by drops in the range of one unit up to sixty four units of volume corresponding to drop diameters selected for printing in the range of one to four. Even when each unit of ink volume is ejected from the printer nozzle with the same momentum, so that the velocity of drop ejection is the same for drops over the range of drop diameters, the drops experience differential air drag depending on the drop diameters. The deceleration of ink drops of small diameter is substantially greater than the deceleration of larger drops, so that the time of arrival of small drops on the print surface is delayed. Accordingly, when there is a relative motion between the printhead and the printing surface during printing, the location of small drops is displaced compared with large drops, the degree of error being most significant when the drop flight path is large and for high printing rates. The effect is also exaggerated in a serial

printhead operating in bi-directional print mode.

It is known to induce electrical charges on drops being formed in an ink jet printer and also to use electric fields to initiate ink drop formation, and to draw and propel the drops towards the print surface. For example, in US-A-3060429 (Winston, assigned to Teletype) ink is selectively drawn out of nozzles containing ink by applying an electric field along the nozzle axis thereby forming an axially directed jet of ink which in turn breaks up into an irregular drop stream. Writing is effected by deflecting the jet in two orthogonal axes normal to the jet axis by deflection electrodes and is initiated and interrupted by modulating the axial field. The pressure behind the nozzles of such a printer is constant and is usually slightly negative, or if it is positive is insufficient to cause ink to flow through the nozzles in the nozzle plate. Further the field is applied to develop a jet comprising all of the ink printed by the nozzle.

In US-A-4403234 (Miura and Naito, assigned to Matsushita) ink is selectively drawn forward out of nozzles in the form of ink drops by applying a pulsed electric field along the axis of a first nozzle supplied with ink, and the drops are then accelerated by means of an axially directed air stream through a secondary nozzle located immediately in front of and co-axial with the first nozzle. Writing is effected by employing an array of nozzles from which ink drops are selectively ejected onto the print surface. As in the previous art referred to, the pressure behind the nozzle containing ink is constant and is maintained at the same pressure as the pressure of the air outside the first nozzle, so that the ink pressure differential is either zero or is insufficient to cause ink to flow through the nozzle plate which retains the ink. At the same time the electric field, which is applied, is pulsed and is used only to draw the ink meniscus forward. Those drops to which the pulsed electric field is applied comprise the whole of the ink drop printed, the drops then being accelerated by air drag in an axially directed air stream.

In further prior art, ink is ejected from a nozzle or nozzles under pressure to form a continuous high speed ink jet as for example in US-A-3596275 (Sweet) and US-A-3298030 (Lewis and Brown). The jet is

at the same time subjected to a high frequency pressure modulation which develops varicosities on the jet causing the jet to break up into a continuous stream of uniform droplets. A charge electrode is placed in the region of jet break-up whereby differential charges may be selectively applied to drops in the drop stream in accordance with electrical signals, character or pattern information. In a printer which uses this system, the stream of drops is next passed through deflection plates which generate a transverse electrical field of high magnitude thereby deflecting drops in accordance with the charge induced on them in the charge electrode and deflecting the drops into locations on a print surface in accordance with the applied charging voltage. In an ink jet printer of this type the pressure causing drop ejection is a continuous high pressure which causes a continuous jet of ink to be formed, and the field which accelerates the charged drops is applied to the entire ink drops printed on the print surface and acts transversely to deflect drops onto selected print locations.

The art to which reference has been directed, uses the effect of an electric field in the formation or deflection of ink drops. It does not address the problem of controlling the motion along the flight path of differently sized droplets ejected through the mechanism of pressure pulses in respective ink channels in a drop-on-demand printer.

It is an object of the present invention to provide improved droplet deposition apparatus which offers the capability of controlling the velocity of ink drops along the axis of the drop flight path in a drop-on-demand printer.

One particular object of the invention, in one of its forms, is to control the velocity of satellite drops formed behind a principal drop in such a way as to reduce or eliminate the deleterious effects of satellite drops on printhead reliability by preventing satellite drops collecting on the nozzle plate.

Another objective is to reduce or eliminate the deleterious effects of satellite drops on print quality by causing satellite drops to merge with the principal drop in flight or in the dot formed on the print surface.

An object of the invention, in another form, is to control the velocity of

variable sized ink drops during variable tone printing of a drop–on–demand ink jet printer in such a manner as to compensate for the effect of variable air drag with drop size and to reduce errors in the accuracy of print location between drops of different size.

Accordingly, the present invention consists in one aspect in a method for controlling velocity along the nozzle axis of ink drops ejected from nozzles of a drop–on–demand printer by means of pressure pulses formed in ink chambers communicating with those nozzles, comprising the steps of establishing an electrical field along the nozzle axis; inducing an electrical charge in the drops, and accelerating the drops by action of the electric field on the charge retained by the drops, in such a manner as to control drop velocity along the nozzle axis.

In a further aspect, the invention consists in a method for reducing the deleterious effects of satellite drops, formed from fluid in the ligament which stretches between a principal drop and the nozzle plate of a drop–on–demand ink jet printer, the printer being of a type wherein the principal drop is ejected from a nozzle in the nozzle plate by means of a pressure pulse formed in the ink in a chamber behind the nozzle plate in response to a pulsed electrical print signal; comprising the steps of establishing an electrical field along the nozzle axis, inducing an electrical charge in the principal emerging drop and the ligament prior to break up and accelerating the satellite drops formed by the fluid in the ligament after break–off by action of the electric field on the charge retained by the satellite drops, thereby causing the drops to accelerate toward the principal drop in flight.

In still a further aspect, the invention consists in a method of compensating for differential air drag between differently sized drops of ink ejected from a drop–on–demand ink jet printer, the printer being of a type in which drops are ejected from a nozzle by means of a pressure pulses formed in an ink chamber in response to a pulsed electrical print signal; comprising the steps of establishing an electrical field along the nozzle axis; inducing an electrical charge in the drops, and accelerating the drops by action of the electric field on the charge retained by the drops, in such a

manner as to compensate for differential air drag.

The invention will now be described by way of example by reference to the following diagrams in which:–

Figure 1 illustrates a drop–on–demand ink jet head from which drops are ejected followed by a chain of satellite drops;

Figure 2 illustrates the accumulation of charges on the print surface as a result of positive tribologically charged drops, which repel satellites away from the print surface, falling onto the printhead and nozzle plate;

Figure 3 illustrates an electric field arrangement which can be used for the control of satellites formed in a drop–on–demand ink jet printhead by the establishment of an axially directed electrostatic field and acceleration of the satellites towards the principal ink drop causing the satellites to merge with the printed dot formed thereby on the print surface;

Figure 4 is a view similar to Figure 3, illustrating a modification; and

Figure 5 is a scrap view, to an elongated scale, illustrating a modification to the nozzle plate of Figure 3 or Figure 4.

Figure 1 shows in diagrammatic form a drop–on–demand ink jet printhead 10 from which ink drops 12 are ejected from nozzles 14 on to a surface 16. The emerging drops are illustrated from left to right in progressively later stages of drop formation, and again at a later time after landing as dots 18 on the printing surface. The printhead referred to comprises any suitable form of drop ejector in which a pressure pulse is formed selectively in chambers behind the nozzles in response to electrically applied pulses, as for example a thermal or bubble jet printer (for example US–A–4251824 (Hara) and US–A–4296421(Hara)) or a piezo–electrically actuated printhead using individual actuators (for example US–A–2512743 (Hansell), US–A–3946398 (Kyser & Sears) and US–A–3683212 (Zoltan)) or array piezo–electric actuators (for example US–A–4879568 (Bartky) and US–A–4887100 (Bartky)).

When ink drops are ejected in excess of a certain velocity, the emerging drop trails a fluid ligament which is drawn out between the drop and the ink meniscus in the nozzle for a substantial period before drop

break-off. The shape of the pendant drop prior to break-up is thought to be regulated in accordance with the non-dimensional velocity or Weber Number and the viscosity number. These are given by:-

$$\text{Weber Number } We = u\sqrt{\frac{\rho D}{\sigma}}$$

$$\text{Viscosity Number} = \frac{\mu}{\sqrt{\rho D \sigma}}$$

where u is the drop velocity (ms^{-1});

ρ is the ink fluid density ($kg\ m^{-3}$);

D is the diameter (m);

σ is the ink surface tension (N_m^{-1}) (N^{m-1} ; and

μ is the ink fluid viscosity (Pa.s.).

In particular, the ligament persists significantly when We>5.

When drop break-off occurs, the ligament also breaks up into a chain of satellites. At lower values of We, one or two satellites are formed moving towards the drop, so that they eventually merge. Consequently the satellites are collected on the print surface 16 in the printed dot 18. At higher values of We, however, a longer ligament breaks up into a larger number of satellites. Four are illustrated in Figure 1, and sometimes at higher velocities as many as six are observed. Being formed from a more highly stretched ligament, satellites in greater numbers are smaller and irregular in size. They are also formed with a lower and generally irregular forward velocity, and being smaller are also subject to greater air drag retarding them in the air behind the drop. Satellites formed at a higher drop velocity tend not to merge with the co-formed principal ink drop.

Observation of a printhead using stroboscopic pulses of light triggered with a variable delay when the principal drops are ejected at We>5 often

shows stray satellites drifting in front of the nozzle plate under the influence of local random draughts. Such drops eventually land on exposed surfaces, where the ink spreads making the printhead dirty. In particular some droplets fall back on the nozzle plate. One important objective for printhead reliability and hygiene is to prevent satellite formation, or if satellites do form, to cause them to accelerate towards the principal drop or to merge with the ink dot which it forms on the print surface to prevent them from falling back on the nozzle plate. These considerations are particularly important for drop-on-demand printers operating at high velocity where We>5.

Tests with an operating printhead show that the drops ejected from the nozzles are often charged, causing the print surface to accumulate charge of one polarity while charge of the opposite polarity remains in the printhead. This observation is described by reference to Figure 2.

Figure 2 shows a drop-on-demand printhead 20 having nozzles 24 which generate drops 22 during operation as a result of pressure pulses developed behind the nozzles. The drops land on a print surface 26 where through evaporation or absorption they form printed dots 28. Charge of tribological origin is carried on the drops when they are formed. The polarity of the charge is believed to depend whether the preponderance of surface active molecules on the free meniscus of the ink drops is positive or negative.

In Figure 2 the print surface is electrically isolated or is supported on an insulated platen 30 which is, therefore, isolated viz 31. The ink used generates a positive tribological charge. Printer operation causes ink to be deposited and positive charge to accumulate on the print surface. This is demonstrated by connecting an electrostatic voltmeter between the print surface and the printhead. This shows a build up of a voltage difference reflecting accumulation of charge in the print surface as a consequence of printing. The test described by reference to Figure 2 also results, when operating, in the deposition of satellites and the build-up of ink on the printhead and nozzle surface. This occurs to the highest degree when the printhead and the ink supply is also electrically isolated 32 but still occurs

when the printhead is earthed 34. Build up of ink on the printhead 20 primarily occurs when the print surface 26 and platen 30 behind it are isolated, although some satellites are deposited when these surfaces are earthed, but at a lower rate.

The above test results may best be understood by considering the accumulation of electrical charges and the development of voltage fields as a result of printing. Figure 2 illustrates the printhead 20 generating ink drops 22 charged with a positive polarity and depositing them upon the print surface 26. Positive charges thus accumulate and a voltage field is developed between the print surface and the actuator. The field is increased if the printhead is also isolated electrically 32 rather than earthed 34. The voltage field in the flight path of the drops acts in the direction so as to apply an electrostatic force to the leading ink drops and following satellite drops opposing their flight onto the paper. The retardation of the satellite drops, however, is the most apparent, since their charge/mass ratio is significantly greater. Consequently the satellite drops are retarded, both by electrostatic repulsion and as well as by air drag which is also greater for drops of smaller mass. The satellite drops are then attracted electrostatically or drift onto the printhead and nozzle plate.

It will be recognised that even without electrostatic forces, satellite drops are retarded by air drag. A cloud of free satellites is then seen floating around an ink jet printhead subject to local air draughts. When this ink mist settles, it is eventually observed to deposit on the printer surfaces and represents a reliability and hygiene limitation on printer operation. When charges accumulate on the print surface, so that electric fields are established, the rate of deposition of stray satellites on the nozzle plate adjacent operating nozzles is, however, significantly increased, making the print quality deteriorate more rapidly.

If the ink instead of forming positively charged drops, generates negative charges of tribological origin, then the drops and satellites are negative and the charge which accumulates on the print surface is also negative. The resulting field, however, has the same effect of retarding

satellite drops and returning them onto the printhead and nozzle plate.

Figure 3 illustrates an embodiment of the invention, in which an electric field is established in the flight path of a drop–on–demand ink jet printer between the nozzle plate and the print surface to accelerate the satellite drops onto the print surface and prevent their collection on the printhead. The drop–on–demand printhead 40 in Figure 3 comprises the type of printhead in which drop ejection is effected by a pressure pulse which is selectively developed in pressure chambers behind the nozzles 44 in response to electrically applied pulses. The invention is applicable particularly under conditions where the drop velocity falls in the regime We>5 or when the ligament, which stretches between a drop 42 and the nozzle 44 or between the drop 42 and a subsequently formed drops, forms two or more satellite drops at break–up.

It is advantageous for printer reliability and hygiene to cause the satellite drops to be accelerated into the principal drop and merge with the printed ink dot which it forms on the print surface.

The field illustrated in Figure 3 is obtained by establishing a voltage V in a platen 50 in or behind the print surface 46 at a distance H from the nozzle plate 45. A field $E = V/H$ is thereby established. The magnitude of the field is within the range $0.05 < E < 5$ volts per μm and, preferably, within the range $0.4 < E < 4.0$ volts per μm. The breakdown strength of air is generally measured to be 5000 volts over 1mm or 5 volts per μm. It will be realised that the magnitudes herein are provided to illustrate typical ranges, and may vary with the drop sizes and scale of the printhead.

A drop 42 ejected from the printhead 40 is shown in Figure 3 from left to right in progressively later stages of drop formation. As previously discussed the emerging drop trails a fluid ligament which stretches between the drop 42 and the nozzle 44 for a substantial period before drop break–off. At break–off of the principal drop 42, the ligament also breaks up forming satellite drops 43–1, 43–2, 43–3 etc. The potential at the emerging drop 42 immediately before break–off of the drop is f_1V. The potential at other locations along the ligament where a satellite may form is denoted f_2V and

f_3V etc., where f_1, f_2 and f_3 are fractions representing the fraction of the distance H between the nozzle plate 45 and the print surface 46 where the principal drop 42 or a satellite drop 43-2, 43-3 is formed.

In general an ink jet ink is conductive so that the potential of the principal drop 42 and the ligament, prior to break-off is the same as the potential of the printhead, or of the ink in the printhead. This potential may be defined as datum or V=0. When the emerging drop is located at potential f_1V, since the ink drop itself is at a potential V=0, equilibrium is maintained by the flow of charge along the ligament and the formation of surface charges on the drop surface of opposite polarity to the potential V. Corresponding charges are also established at locations on the ligament in equilibrium with the local potential f_2V and f_3V. Although f_2 and f_3 are less than f_1, the charge density on the ligament surface prior to break-up is generally greater than on the principal drops, because the radius of the ligament is substantially lower than that of the principal drop.

At break-up, accordingly, the satellite drops are charged and have a substantially greater charge/mass ratio than the principal drop. The polarity of the charges is of opposite polarity to the applied voltage V and, therefore, is such as to accelerate the satellite drop forward along the flight path towards the principal drops. They eventually merge either with the principal drop in flight or into the printed dot formed by the principal drop on the print surface.

When V/H is in the range 0.05 to 0.5 the charge/mass ratio of the principal drop is relatively small, so that no significant forward acceleration of the principal drop is observed. At higher voltage levels ($V/H > 5.0\ V/\mu m$), the satellite charge magnitudes may prove excessive, so that adjacent satellites repel one another in flight and may be deflected from their flight path on the nozzle axis, causing them to land on the print surface outside the footprint of the printed dot. Some forward acceleration of the principal drop can also occur.

In the range $V/H < 0.05\ V/\mu m$, the charge magnitudes induced on the satellite drop, particularly satellite drops formed from regions of the ligament

nearest to the nozzle plate, are of reduced magnitude and may be of the same order as tribological charge. If the tribological charge is of the same polarity as the induced charge the desired acceleration of the satellite is observed to a small degree, but when the tribological charge is of opposite sign to the induced charge, the applied field may repel the satellite drops formed near the nozzle plate, which can be repelled back onto the nozzle plate. It must be noted however that the charge forces are small at these low field strengths and air drag from random draughts also is in evidence.

More generally, it can be seen that increased certainty that satellite drops will be accelerated towards the print surface to merge with the printing drops is obtained when the tribological charge and the charge induced on the satellites are arranged to have the same rather than opposite sign, and therefore satellite control can be provided at a lower magnitude of applied voltage.

The field has been described as being established in the direction of the nozzle axis by applying a voltage V relative to a datum voltage 0 in the printhead. The voltage V in Figure 3 is shown as applied to an electrode in the form of a platen 50 behind the print surface. The field may be established by alternative means. For example the voltage may be applied directly to the print surface as electrode or in the case of an insulating or isolated print surface charge may be applied to or adjacent the print surface by an external source, such as a plasma generator or a corona wire, or from a radio active or piezo-electric source. Alternatively, as shown in Figure 4, an electrode 60 may be located between the print surface 62 and the nozzle plate 64 to deploy a field for charging and for drop acceleration in the upper region of the flight path between the electrode and the nozzle plate. Such an electrode may extend conveniently in the array direction parallel to the nozzle plate, and will be apertured to provide free passage for drops.

The datum voltage V=0 is provided by the potential of the ink which is conductive. However, other datum electrodes may be employed in the printhead as for example a conducting layer in the nozzle plate . Alternatively a conducting layer may be deposited on internal surfaces of the

ink channels in which pressure pulses are developed, the layer being connected through the ink, or to an external connection to earth. This serves to maintain the potential of the ink at the nozzle exit at datum.

Since the requirement is to establish an electric field along the nozzle axis, it will be evident that the paper or the platen behind it may be held at V=0, and the ink or electrodes in contact maintained at a voltage ±V, and that a similar degree of control of satellites is then achieved.

The charge induced in the satellite drops is described as being induced by reason of potential f_2V, f_3V at the location where the satellites are formed in the ligament. It will be evident that separate satellite charging electrodes may be established, perhaps taking a similar form to the field electrode shown in Figure 4., or as electrodes partially or wholly surrounding the emerging drop ligament. Although such added electrodes detract from the essential simple construction of a drop–on–demand printing device where the nozzle plate is 1–2mm from the print surface, they become advantageous where the flight path is greater and the drop ejection velocity generally higher. In such a case both the charge electrode and field electrode may be located between the nozzle plate and the print surface and in one form extend conveniently parallel to the nozzle plate along the length of the nozzle array in the array direction. This maximises the clearance between the printhead and the print surface which is advantageous in industrial applications.

A conductive surface in contact with the ink in the printhead may be used to control the potential of the ink in the nozzle. For example, a conductive layer may be provided in the nozzle plate as illustrated in Figure 5. This layer 68 is made typically by vacuum deposition of a metal film onto the outer face of the nozzle plate 70. In a subsequent process step the nozzle plate is provided with a low energy or "non–wetting" coating 72 as for example disclosed in US–A–5010356 (EP–A–03674838). After applying the nozzle plate to the ink jet printhead, nozzles are formed (as shown) connected to each ink channel. The conducting layer is then connected to the earth rail in the printhead drive circuit.

During operation the conducting layer provides an electric contact to the ink and therefore serves to control the potential of the ink in the nozzle. The same function can be obtained by a conductive metal coating over the channel walls in the printhead connected to earth potential.

The application of an axial electrical field along the drop flight path and the induction of charges on drops ejected in response to a pressure pulse in a drop–on–demand printer, also finds application in a variable tone printer ejecting variable sized drops. In such a printer the range of volume of the ink drop ejected from each nozzle in the printhead can vary from 1 unit of volume to 64 units of volume, corresponding to a range of drop diameters of 1 – 4. Typically the drop diameters are produced in a range around 12μm – 50μm. The drop ejection mechanism ejects each unit of volume from the nozzle with approximately equal momentum in response to applied pressure pulses, so that the drops are formed with approximately equal velocity over the range of drop diameters.

Air drag however tends to retard smaller drops more than larger, so that their average velocity in the flight path is lower and so that they arrive on the print surface retarded compared with the larger drops. As a result the smaller drops are displaced in the print surface due to relative motion between the printhead and the print surface, which detracts from the print quality. The displacement error depends on the initial drop velocity, the frequency of drop formation, and the length of the flight path.

In the presence of a electric field and a drop charging electrode system, which induces charge in the printed drops, however, the charge to mass ratio and thus the acceleration of smaller drops is greater than that obtained in larger drops. Typically the acceleration varies according to the exponent D^2; at the same time air drag, which is greater for smaller drops varies with the exponent $D^{1.6}$ to D^2. Thus a magnitude of electrostatic field can be found that overcomes the additional air drag of the smallest drops and those of intermediate size of drop, and which causes them to arrive at the print surface at approximately the same time as the larger drops, substantially compensating for differential air drag as drop sizes vary in the

operation of a variable tone printer. This is effected by an electrode system substantially the same as that illustrated in Figure 3 and discussed above on pages 11–12 with reference to control of satellite velocity. In the satellite case the small satellite drops are accelerated along the nozzle axis to merge with the principal drop, while moving substantially in the slip stream of that drop. In the variable tone printer each drop may be subjected to air drag in air that is substantially at rest, so that the acceleration due to the charge and the applied field may be used to compensate for the differential arrival time of drops over a range of drop sizes.

CLAIMS

1. A method for controlling velocity along the nozzle axis of ink drops ejected from nozzles of a drop–on–demand printer by means of a pressure pulses formed in ink chambers communicating with those nozzles, comprising the steps of establishing an electrical field along the nozzle axis, inducing an electrical charge in the drops, and accelerating the drops by action of the electric field on the charge retained by the drops, in such a manner as to control drop velocity along the nozzle axis.

2. A method according to Claim 1, wherein said ink drops vary in size and wherein drop velocity is controlled differentially with drop size.

3. A method according to Claim 2, wherein the differential control serves to render drop velocity sensibly constant, irrespective of drop size.

4. A method according to Claim 2, wherein the differential control serves to accelerate a small satellite drop relatively to a principal drop associated therewith, thereby to cause amalgamation of the satellite and principal drops.

5. A method according to Claim 4, wherein the Weber Number of the ink drop is We > 5.

6. A method according to any one of the preceding claims, wherein the step of inducing electrical charge in the drops, comprises exposing the emerging ink ligament to a charging field prior to break–off of the drops from the nozzles.

7. A method according to Claim 6, wherein the charging field is the said electrical field established along the nozzle axis.

8. A method according to any one of Claims 1 to 5, wherein the step of

inducing electrical charge in the drops, comprises tribologically charging the drops.

9. A method according to Claim 6, wherein said charge induced in the drops has the same polarity as a tribo–electrically induced charge in the drops.

10. A method according to any one of the preceding claims, wherein the magnitude E of said electrical field is within the range:–
$0.05 < E < 5V/\mu m$.

11. A method according to Claim 10, wherein E is within the range:–
$0.4 < E < 4.0\ V/\mu m$.

12. A method for reducing the deleterious effects of satellite drops, formed from fluid in the ligament which stretches between a principal drop and the nozzle plate of a drop–on–demand ink jet printer, the printer being of a type wherein the principal drop is ejected from a nozzle in the nozzle plate by means of a pressure pulse formed in the ink in a chamber behind the nozzle plate in response to a pulsed electrical print signal; comprising the steps of establishing an electrical field along the nozzle axis, inducing an electrical charge in the ligament prior to break up and accelerating the satellite drops formed by the fluid in the ligament after break–off by action of the electric field on the charge retained by the satellite drops, thereby causing the drops to accelerate toward the principal drop in flight.

13. A method according to Claim 12, wherein the satellite drops are caused to merge with the principal drop in flight.

14. A method according to Claim 12, wherein the satellite drops are caused to merge with the principal drop on the print surface to form a single printed dot.

15. A method according to any one of Claims 12 to 14, wherein the Weber Number of the ink drop is We>5.

16. A method according to any one of Claims 12 to 15, wherein said electrical field serves to induce said electrical charge in the principal emerging drop and the ligament prior to break up.

17. A method according to any one of the Claims 12 to 16, wherein said electrical field is established by means of electrodes spaced apart along the drop flight path.

18. A method according to Claim 17, wherein conducting ink in said chambers serves as one of said electrodes.

19. A method according to Claim 17, wherein a conductive surface in contact with the ink serves as one of said electrodes.

20. A method according to Claim 17, wherein a conducting layer on the nozzle plate serves as one of said electrodes.

21. A method according to Claim 17, wherein one of said electrodes is associated with the print surface.

22. A method according to Claim 17, wherein one of said electrodes is positioned in space between the nozzle plate and the print surface.

23. A method according to any one of the Claims 12 to 16, wherein said electrical field is established by the developing or depositing of electrical charge on said print surface.

24. A method according to Claim 23, wherein the means for depositing charge is selected from the group consisting of corona wire or other plasma

induced charge means, radioactively induced charge means and piezo–electrically developed charge means.

25. A method according to any one of Claims 12 to 24, wherein said charge retained in the satellite drops has the same polarity as a tribo–electrically induced charge in the drops.

26. A method of compensating for differential air drag between differently sized drops of ink ejected from a drop–on–demand ink jet printer, the printer being of a type in which drops are ejected from a nozzle by means of a pressure pulses formed in an ink chamber in response to a pulsed electrical print signal; comprising the steps of establishing an electrical field along the nozzle axis; inducing an electrical charge in the drops, and accelerating the drops by action of the electric field on the charge retained by the drops, in such a manner as to compensate for differential air drag.

27. A method according to Claim 26, wherein the printer is capable of ejecting drops in 8 or more discrete sizes and wherein each drop is accelerated in relation its mass and drag resistance so as to render the time of drop flight sensibly independent of drop size.

28. A method according to Claim 26 or Claim 27, wherein the step of inducing electrical charge in the drops, comprises exposing the drops to a charging field prior to break–off of the drops from the nozzles.

29. A method according to Claim 28, wherein the charging field is said electrical field established along the nozzle axis.

30. A method according to any one of Claims 26 to 29, wherein the magnitude E of said electrical field is within the range:–
$0.05 < E < 5V/\mu m$.

31. A method according to Claim 30, wherein E is within the range:– $0.4 < E < 4.0\ V/\mu m$.

32. Drop–on–demand ink jet printing apparatus, comprising an array of parallel ink channels, a plurality of nozzles communicating respectively with the channels and means for applying pressure pulses to selected channels to effect drop ejection from the respective nozzles thereof, for deposition on a print surface, characterised in that charging means are provide for inducing an electrical charge in the drops and in that field means are provided to establish an electrical field along the nozzle axis, for applying a force to the drops by action of the electric field on the charge retained by the drops, in such a manner as to control drop velocity along the nozzle axis.

33. Apparatus according to Claim 32, wherein said ink drops vary in size and wherein drop velocity is controlled differentially with drop size.

34. Apparatus according to Claim 33, wherein the differential control serves to render drop velocity sensibly constant, irrespective of drop size.

35. Apparatus according to Claim 33, wherein the differential control provides that satellite drops formed by ink in an ink ligament after drop break–off are accelerated by action of the electric field on the charge retained by the satellite drops, thereby causing the satellite drops to accelerate toward the principal drop in flight.

36. Apparatus according to Claim 35, wherein the Weber Number of the ink drop is $We > 5$.

37. Apparatus according to Claim 35 or Claim 36, wherein the electrical field generated by said field means serves to induce said electrical charge in the principal emerging drop and the ligament prior to break up.

38. Apparatus according to any one of Claims 33 to 37, wherein said field means comprises electrodes spaced apart along the drop flight path.

39. Apparatus according to Claim 38, wherein conducting ink in said channels serves as one of said electrodes.

40. Apparatus according to Claim 37, wherein a conductive surface in contact with the ink serves as one of said electrodes.

41. Apparatus according to Claim 38, wherein said electrodes include an electrode integral with the nozzle plate at the ink polarity.

42. Apparatus according to any one of Claims 38 to 41, wherein said electrodes include an electrode adjacent said print surface.

43. Apparatus according to any one of Claims 38 to 41, wherein said electrodes include an electrode positioned between the nozzle plate and said print surface.

44. Apparatus according to Claim 33, wherein said field means comprises means for developing or depositing charge on said print surface.

45. Apparatus according to Claim 44, wherein said means for depositing charge is selected from the group consisting of corona wire or other plasma induced charge means, radioactively induced charge means and piezo–electrically developed charge means.

46. Apparatus according to any one of Claims 33 to 37, wherein said charging means comprises charge electrode means adjacent said nozzles.

47. Apparatus according to any one of Claims 33 to 46, wherein the magnitude E of said electrical field is within the range:–

$0.04 < E < 4V/\mu m$.

48. Apparatus according to Claim 47, wherein E is within the range:– $0.4 < E < 4.0\ V/\mu m$.

49. Drop–on–demand ink jet printing apparatus, comprising an array of parallel ink channels, a plurality of nozzles communicating respectively with the channels and means for applying pressure pulses to selected channels to effect drop ejection from the respective nozzles thereof, for deposition on a print surface, there being a ligament associated with each ejected drop having a tendency to break up into one or more satellite drops, characterised in that charging means are provide for inducing an electrical charge in the ligament prior to break up and in that field means are provided to establish an electrical field along the nozzle axis, such that satellite drops formed by the fluid in the ligament after break–off are accelerated by action of the electric field on the charge retained by the satellite drops, thereby causing the satellite drops to accelerate toward the principal drop in flight.

50. Apparatus according to Claim 49, wherein the Weber Number of the ink drop is We > 5.

51. Apparatus according to Claim 49 or Claim 50, wherein the electrical field generated by said field means serves to induce said electrical charge in the principal emerging drop and the ligament prior to break up.

52. Apparatus according to any one of the Claims 49 to 51, wherein said field means comprises electrodes spaced apart along drop flight path.

53. Apparatus according to Claim 52, wherein conducting ink in said channels serves as one of said electrodes.

54. Apparatus according to Claim 52, wherein a conductive surface in contact with the ink serves as one of said electrodes.

55. Apparatus according to Claim 52, wherein said electrodes include an electrode integral with nozzle plate at the ink polarity.

56. Apparatus according to any one of Claims 52 to 55, wherein said electrodes include an electrode adjacent said print surface.

57. Apparatus according to any one of Claims 52 to 55, wherein said electrodes include an electrode positioned between the nozzle plate and said print surface.

58. Apparatus according to Claim 51, wherein said field means comprises means for depositing charge on said print surface.

59. Apparatus according to Claim 58, wherein said means for depositing charge is selected from the group consisting of corona wire or other plasma induced charge means, radioactively induced charge means and piezo–electrically developed charge means.

60. Apparatus according to Claim 49 or Claim 50, wherein said charging means comprises charge electrode means adjacent said nozzles.

61. Apparatus according to any one of Claims 49 to 60, wherein said charge induced in the satellite drops has the same polarity as a tribo–electrically induced charge in the drops.

62. Drop–on–demand ink jet printing apparatus, comprising an array of parallel ink channels, a plurality of nozzles communicating respectively with the channels and means for applying pressure pulses to selected channels to effect drop ejection from the respective nozzles thereof in eight or more

discrete drop sizes, for deposition on a print surface, characterised in that charging means are provide for inducing an electrical charge in the drops and in that field means are provided to establish an electrical field along the nozzle axis, for accelerating the drops by action of the electric field on the charge retained by the drops, in such a manner as to compensate for differential air drag between differently sized drops.

63. A method according to Claim 62, wherein each drop is accelerated in relation its mass and drag resistance so as to render the time of drop flight sensibly independent of drop size.

Fig.1.

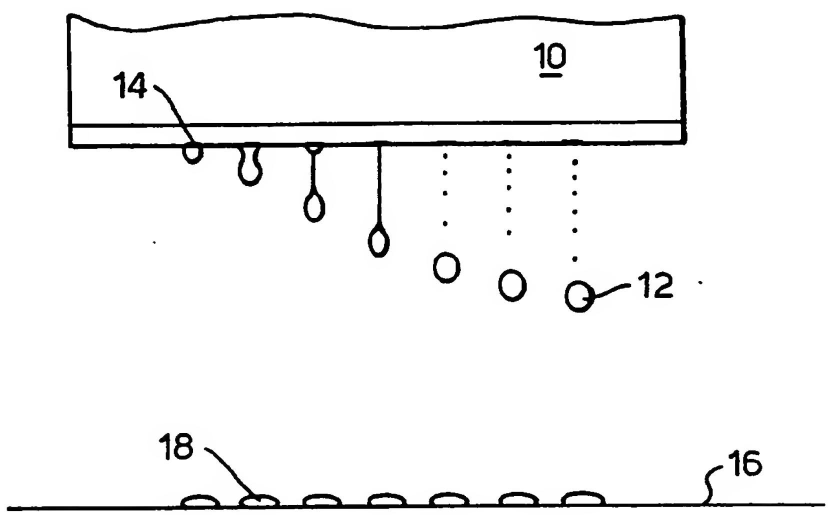
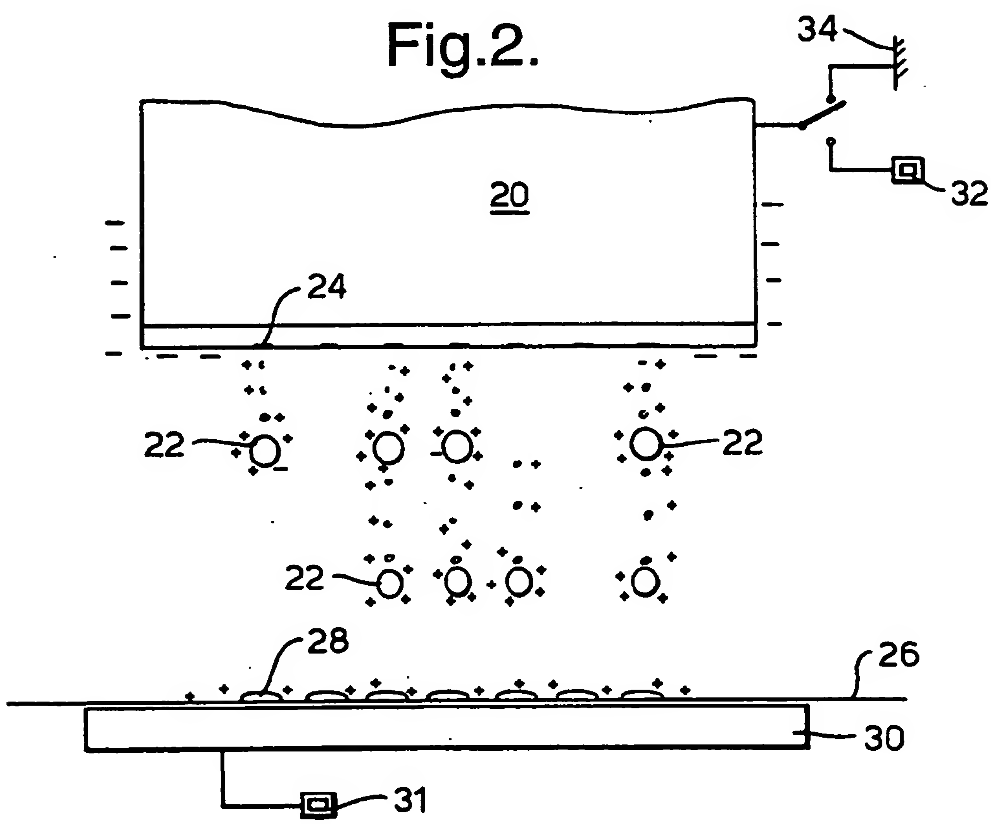


Fig.2.



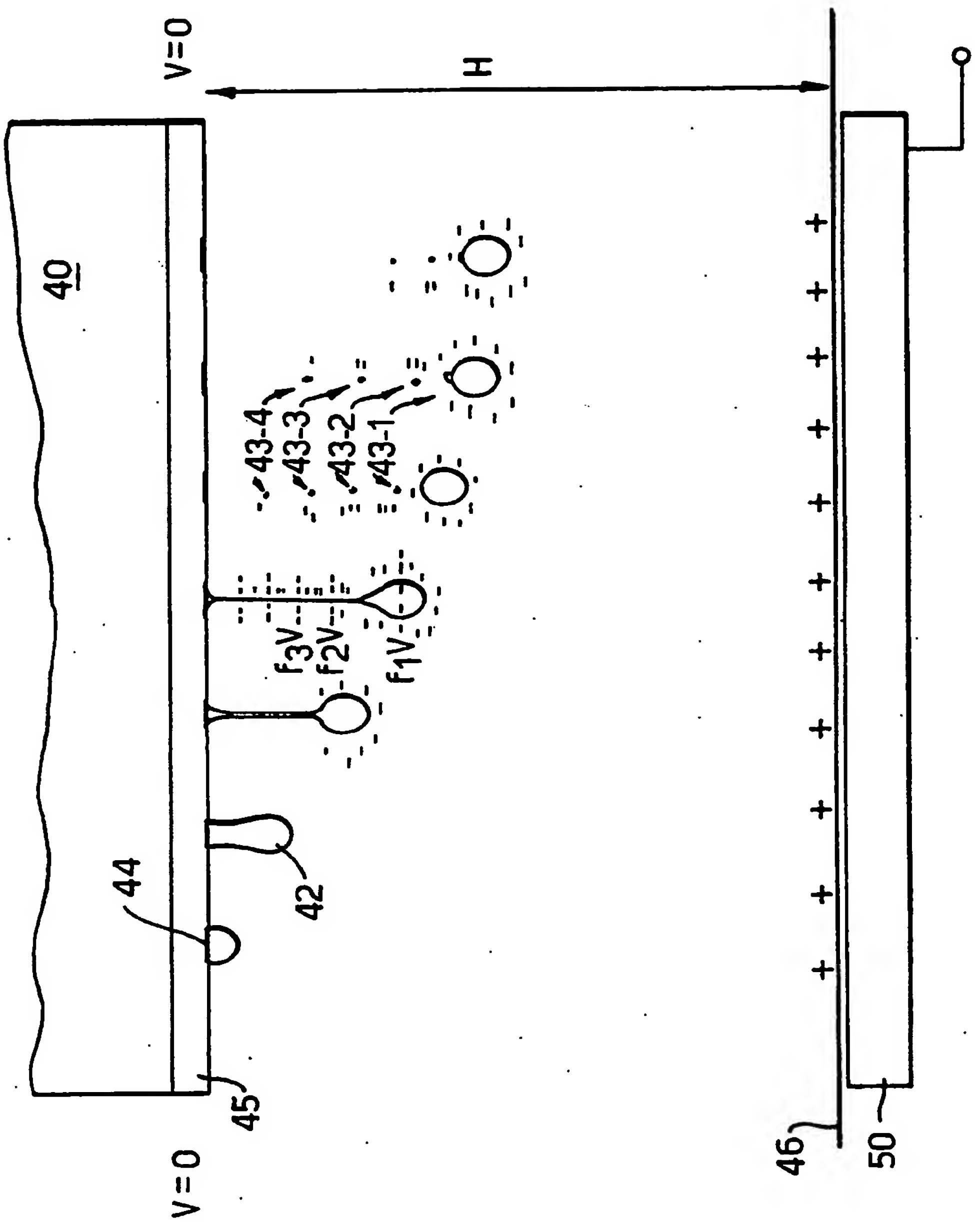


Fig.3.

Fig.4.

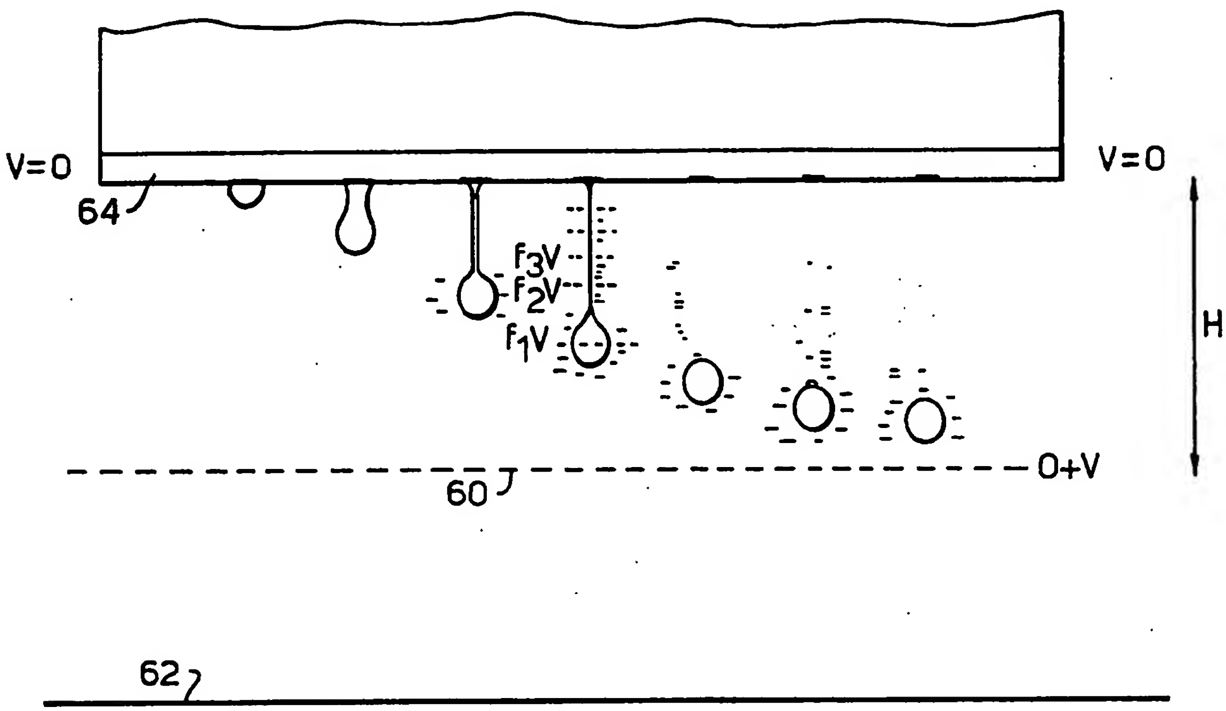
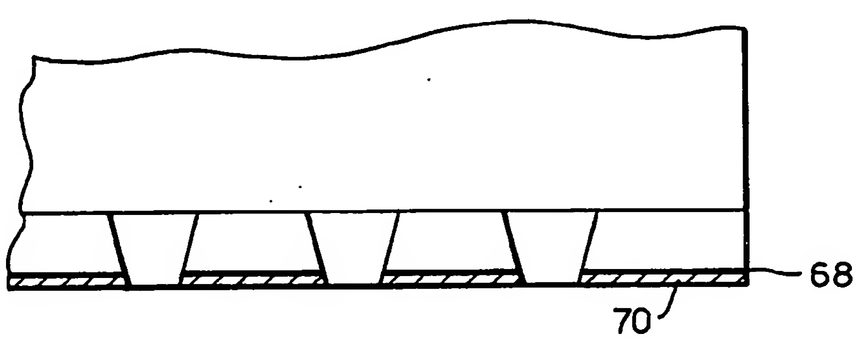


Fig.5.



INTERNATIONAL SEARCH REPORT

Interna d Application No
PCT/GB 94/02381

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   B41J2/115

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6   B41J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP,A,0 473 178 (CANON KABUSHIKI KAISHA) 4 March 1992 see the whole document ---	1,12,32
X	PATENT ABSTRACTS OF JAPAN vol. 5 no. 53 (M-63) [725] ,14 April 1981 & JP,A,56 008272 (RICOH KUBUSHIKI KAISHA) 28 January 1981, see abstract ---	1
A	US,A,4 368 474 (TOGAWA ET AL.) 11 January 1983 see the whole document ---	1-63
A	EP,A,0 473 179 (CANON KABUSHIKI KAISHA) 4 March 1992 see the whole document --- -/--	1-63

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
1 March 1995	29.03.95

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European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Joosting, T

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JOURNAL OF IMAGING TECHNOLOGY, vol. 16, no.1, February 1990 SPRINGFIELD US, pages 43-47, XP 000101464 REZANKA ET AL. 'Satellite Control by Direct Harmonic Excitation' see the whole document	1-63
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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